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(54) Heat exchanger performance monitors.

(57) A performance monitor (20) generates a fouling factor (FF) which indicates the level of fouling of a heat exchanger (10) having a heat exchange surface area and through which passes a heat exchange medium having a known specific heat. Temperature transmitters (TT_1, TT_2, TT_3) are utilised to obtain values for the input and output temperatures of the heat exchange medium as well as the temperature in the heat exchanger of a heat exchange fluid used to transfer heat to or from the heat exchange medium. Modules (30, 40, 50, 60) are used to generate values for an actual heat transfer coefficient (U_{act}) and a nominal heat transfer coefficient (U_{ave}) in the heat exchanger (10) as a function of the temperatures, flow rate and constant parameters such as area and specific heat, for the heat exchanger (10). The actual heat transfer coefficient (U_{act}) is compared with the nominal or original heat transfer coefficient (U_{ave}) to determine if there is any deterioration in the coefficients which reflects fouling of the heat exchanger. A simple ratio of the nominal to actual heat transfer coefficients is taken (61) as a measure of the fouling factor (FF).

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HEAT EXCHANGER PERFORMANCE MONITORS

This invention relates to heat exchanger performance monitors. More specifically, the invention relates to a performance monitor for generating a fouling factor of a heat exchanger.

The performance of heat exchangers can be monitored. Such monitoring, however, requires extensive calculations which, hitherto, have been done using computers and high level programming languages. Such performance calculations have been disclosed in "Trouble-Shooting Compression Refrigeration Systems" by K. J. Vargas, Chem. Engineering, 22 March 1982.

In order to determine the performance capacity of a heat exchanger under various operating conditions, deviations of the heat exchanger from design conditions must be accounted for by these extended calculations.

Experimental data has also been used to determine heat exchanger performance, as described in "Controlling Chiller Tube Fouling" by G. Leitner, ASHRAE Journal, Feb. 1980. Such experimental data is not, however, always available.

Currently, computers are employed to determine the performance of heat exchangers in a prompt manner. The continuous availability of performance measurements helps in diagnosing several problems as they occur. However, computers require high level language and highly trained personnel. This results in high costs for monitoring the heat exchangers.

According to one aspect of the present invention there is provided a performance monitor for generating a fouling factor of a heat exchanger having a heat exchange surface area against one side of which a heat exchange medium passes, the medium having a specific heat value, the performance monitor comprising:
first temperature transmitter means for supplying a signal corresponding to an output temperature of heat exchange medium from the heat exchanger;
second temperature transmitter means for supplying a signal corresponding to an input temperature of medium to the heat exchanger;

used, for example, to determine when a soot blowing operation should be commenced in a boiler.

The invention will now be further described, by way of illustrative and non-limiting example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic block diagram showing an evaporator as an example of a heat exchanger in combination with a performance monitor embodying the present invention;

Figure 2 is a block diagram showing fouling factor monitoring logic of the performance monitor for generating a signal corresponding to a fouling factor of the heat exchanger;

Figure 3 is a block diagram showing a water surface film module used in the circuit of Figure 2;

Figure 4 is a block diagram showing a refrigerant surface film module used in the circuit of Figure 2;

Figure 5 is a block diagram of an analytical heat transfer module used in the circuit of Figure 2; and

Figure 6 is a block diagram of an actual heat transfer module used in the circuit of Figure 2.

The drawings illustrate one embodiment of performance monitor which is particularly useful in monitoring the extent of fouling in a heat exchanger and, in particular, an evaporator.

As noted above, one of the reasons for degraded performance of a heat exchanger is fouling. There are other reasons, such as lack of flow, which may reduce the heat transfer capability. The present monitor, however, isolates the effects of velocity to single out fouling as the cause of degraded heat transfer. The Heat Transfer equation is:

$$q = U.A.Tm \qquad (1),$$

where:

q = heat flow (W or Btu/h),

U = overall heat transfer coefficient ($W/m^2.K$ or $Btu/h.ft^2.^oF$),

A = surface area (m^2 or ft^2), and

Tm = logarithmic mean temperature difference.

The measured (actual) value of U_{act} is compared with its normal value to determine the extent of fouling. The actual value is found from measurements as:

X = wall thickness,
K = thermal conductivity of the tube material,
A_m = mean area,
A_o, A_i = outside and inside areas, and
r_f = fouling factor.

In case U_{ava} is provided by the manufacture of the evaporator, Equation (5) should be checked against the manufacturer's value and should be corrected by a multiplication factor K_f if needed.

The values of h_r, h_w are velocity and temperature dependent and the K value may be temperature dependent. Therefore, these values should be calculated, and U should be updated in order to compare it with the experimental data.

A general formula for the h (film coefficient) value is given by:

$$h = C\frac{K}{d}\left(\frac{Md}{\mu}\right)^n\left(\frac{\mu C_p}{K}\right)^m \qquad (6)$$

where:

d = tube diameter,
M = mass velocity ((g/s.m^2) or lb/(s.ft^2)),
μ = viscosity, and
m,n,C = constants.

The values of m, n, C depend upon the application or type of heat exchanger. Although the form of Equation (6) may differ in special cases such as viscous fluids, the same terms are used.

In the following development of U, h_w and h_r are tested as general non-linear functions of temperature and velocity. The corrections on nominal values of h_r^o and h_w^o, due to the variations of the temperature and the velocity, are made.

The case of an evaporator monitor, as illustrated in Figures 1 to 6, will now be treated. The monitor is applied to a flooded evaporator 10 with water inside tubes shown schematically at 12. The refrigerant velocity will be small as compared with other types of evaporators. However, mass velocity of refrigerant can be taken from measurements of compressor inlet flow at an inlet 16 of a compressor 14 or it can directly be measured from an outlet 17 of a condensor 18. Here, the compressor measurements at its inlet 16 are utilised.

holds. Writing:

$$h_w = h_w^o \frac{h_w}{h_w^o} \qquad (10)$$

where:

$$\frac{h_w}{h_w^o} = \underbrace{\left[\frac{(h_w)^{T_w}}{h_w^o}\right]}_{f_1(T_w)} \underbrace{\left[\frac{(h_w)^{M_w}}{h_w^o}\right]}_{f_2(M_w)} \underbrace{\left[\frac{(h_w)^{T_s}}{h_w^o}\right]}_{f_3(T_s)} \qquad (11)$$

The value of the numerator $f_1\ (T_w)$ is determined from Equation (6) by calculating h_w for various T_w values while the other variables are held at their nominal values M_w^o and T_s^o. The functions "f" are used in Figures 3 and 4.

Water cooled condensers and precoolers can also be monitored in the same way as the evaporator by the monitor embodying the invention. The heat transfer q can either be calculated by measuring condenser water parameters and using Equation (4) or using the refrigerant side measurements. In that case the q value for a condenser is written as:

$$q = M_r \quad (h_{gas} - h_{liq}) \qquad (12)$$

where:

m_r = refrigerant mass flow rate (g/h or lb/h),
h_{gas} = enthalpy of refrigerant entering, and
h_{liq} = enthalpy of refrigerant leaving.

For evaporative and air-cooled condensers it is better to use Equation (12) for q. For air-cooled condensers, water is replaced by air and the same equations apply. ΔT_m is calculated similarly.

For evaporative condensers, there is an intermediate fluid water between refrigerant and air. Determining U_{act} is identical to the other cases. The average value of ΔT_m for refrigerant to water and ΔT_m for refrigerant to air is used as ΔT_m.

For the analytical heat transfer coefficient, three surface film coefficients have to be calculated. Their calculations are covered in Equation (6). A modified relation over Equation (5) is:

The actual heat transfer module 60 is connected to the temperature transmitters TT_1, TT_2 and TT_3, as well as the mass flow logic unit 19. As shown in greater detail in Figure 6, the module 60 generates a value corresponding to the actual heat transfer coefficient U_{act}.

The original or nominal heat transfer coefficient U_{ava} can be used as a known value or can be ascertained using the three modules 30, 40 and 50 shown in Figure 2 and detailed in Figures 3, 4 and 5, respectively.

The nominal or original heat transfer coefficient U_{ava} is divided by the actual value, U_{act}, in a first divider unit 61 to generate the fouling factor FF as described in Equation (7).

Figure 3 shows the water surface film module 30 which uses simple functional units such as summing units 32, multiplication units 34 and a second dividing unit 36, as well as additional somewhat more complicated units, to generate the values h_w and T_s from Equation (6) by the use of Equation (6) and Equations (8) to (11). Optical modules 38 can be used to eliminate the effects of T_w, M_w and T_s.

Function generators 31 are utilised to generate more complex functions, but are also of modular design. These function generators ar utilised to generate the functions needed in Equation (11).

Figure 4 illustrates the refrigerant surface film module 40 for calculating h_r. Here again, function generators 41 are utilised for generating the various functions needed for example in Equation (11), as well as multipliers 44 and summing units 42. Optional modules 43, which are similar to the modules 38 of Figure 3, are also provided.

Figure 5 illustrates the analytical heat transfer module 50 which is connected to the water surface film module 30 and refrigerant surface film module 40, and is also made up of simple functional units such as summing units 52, a multiplier 54 and a divider unit 56. The module 50 implements Equation (5) to calculate the nominal or original heat transfer coefficient U_{ava} as a function of h_w and h_r, supplied from the units 30 and 40, respectively. The structural data as described in Equation (5) is also utilised.

Figure 6 illustrates the actual heat transfer module 60 which is used to run through Equations (2), (3), and (4) for calculating the actual heat transfer coefficient U_{act}. Difference units 63 obtain the various differences between the temperatures as supplied by the temperature transmitters TT_1, TT_2 and TT_3. A mass flow meter 67 (of known structure) supplies the mass

CLAIMS

1. A performance monitor for generating a fouling factor of a heat exchanger having a heat exchange surface area against one side of which a heat exchange medium passes, the medium having a specific heat value, the performance monitor comprising:

first temperature transmitter means (TT_1) for supplying a signal corresponding to an output temperature (T_{cold}) of heat exchange medium from the heat exchanger (10);

second temperature transmitter means (TT_2) for supplying a signal corresponding to an input temperature (T_{hot}) of medium to the heat exchanger (10);

third temperature transmitter means (TT_3) for supplying a signal corresponding to a temperature of the heat exchanger (10) on an opposite side of the heat exchange surface area;

mass flow rate means for supplying a signal corresponding to a mass flow rate of medium through the heat exchanger (10);

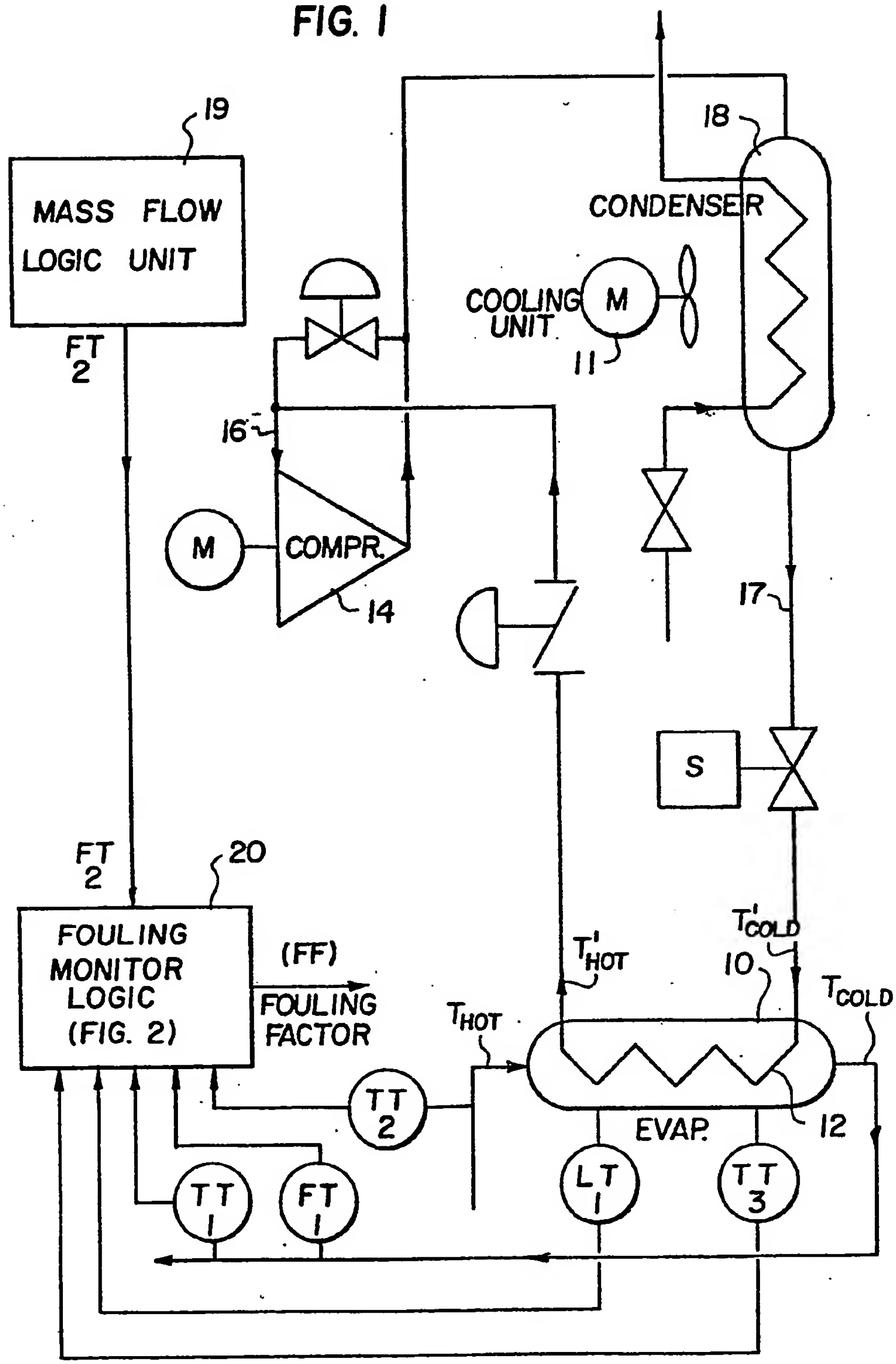
an actual heat transfer module (60) connected to the first, second and third temperature transmitter means (TT_1, TT_2, TT_3) and to the mass flow rate means for calculating an actual heat transfer coefficient (U_{act}) as a function of the input, output and heat exchanger temperatures, the mass flow rate, specific heat value and surface area;

nominal heat transfer co-efficient means for supplying a signal corresponding to a nominal heat transfer coefficient (U_{ava}); and

a divider unit (61) connected to the actual heat transfer module (60) and the nominal heat transfer coefficient means for obtaining a ratio of the nominal to actual heat transfer coefficients which corresponds to the fouling factor (FF).

2. A performance monitor according to claim 1, wherein the nominal heat transfer coefficient means comprises a heat exchange medium surface film module (30) for calculating a film coefficient of the heat exchange medium as a function of the input and output temperatures of the medium and a flow rate of the medium through the heat exchanger (10), the heat exchanger including a heat exchange fluid passing therethrough on the

FIG. 1


MASS FLOW LOGIC UNIT
19
FT 2
CONDENSER
18
COOLING UNIT
M
11
16
M
COMPR.
14
17
S
FT 2
20
FOULING MONITOR LOGIC (FIG. 2)
(FF)
FOULING FACTOR
T'HOT
T'COLD
10
TCOLD
THOT
12
EVAP.
TT 2
TT 1
FT 1
LT 1
TT 3

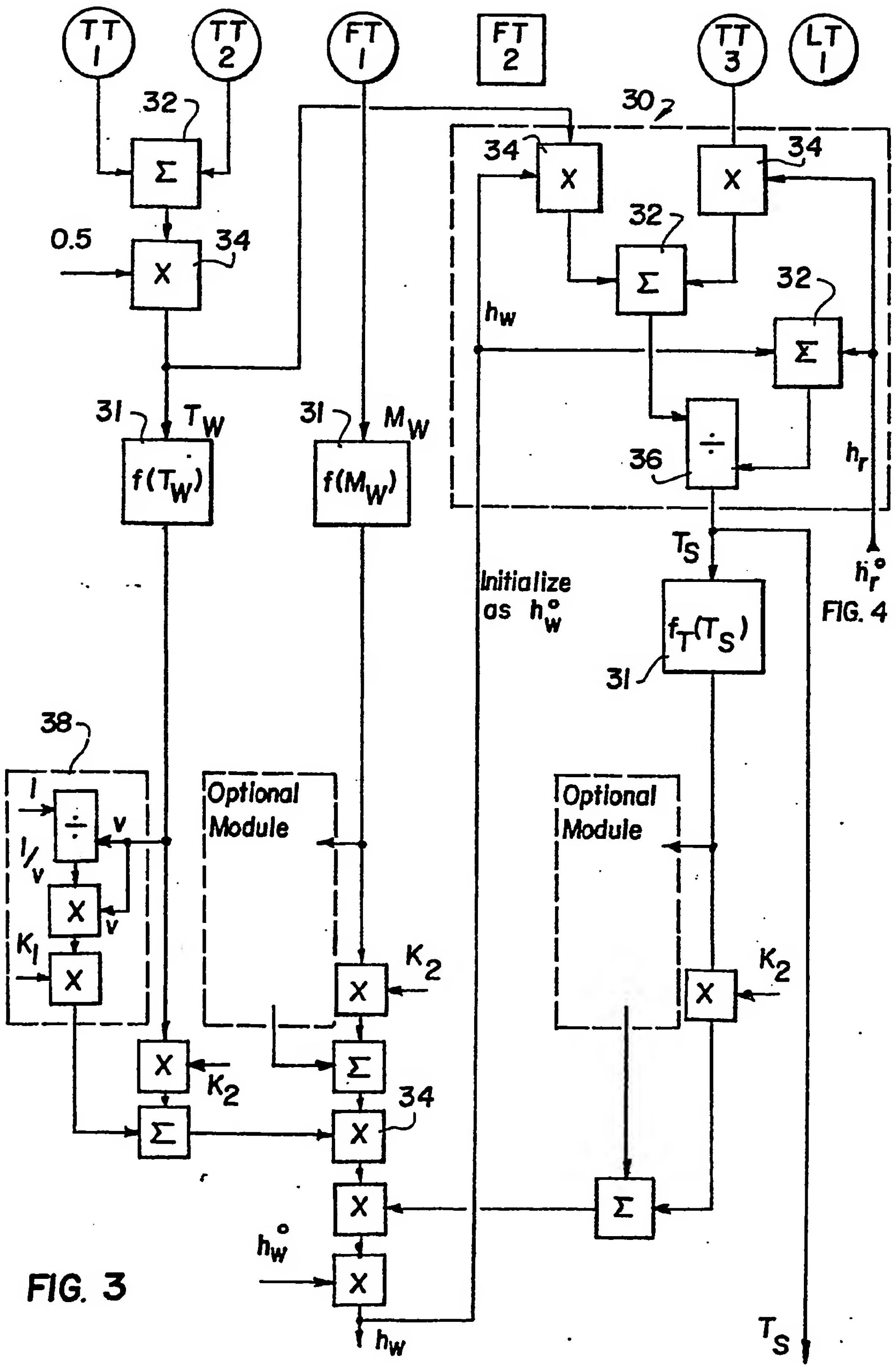
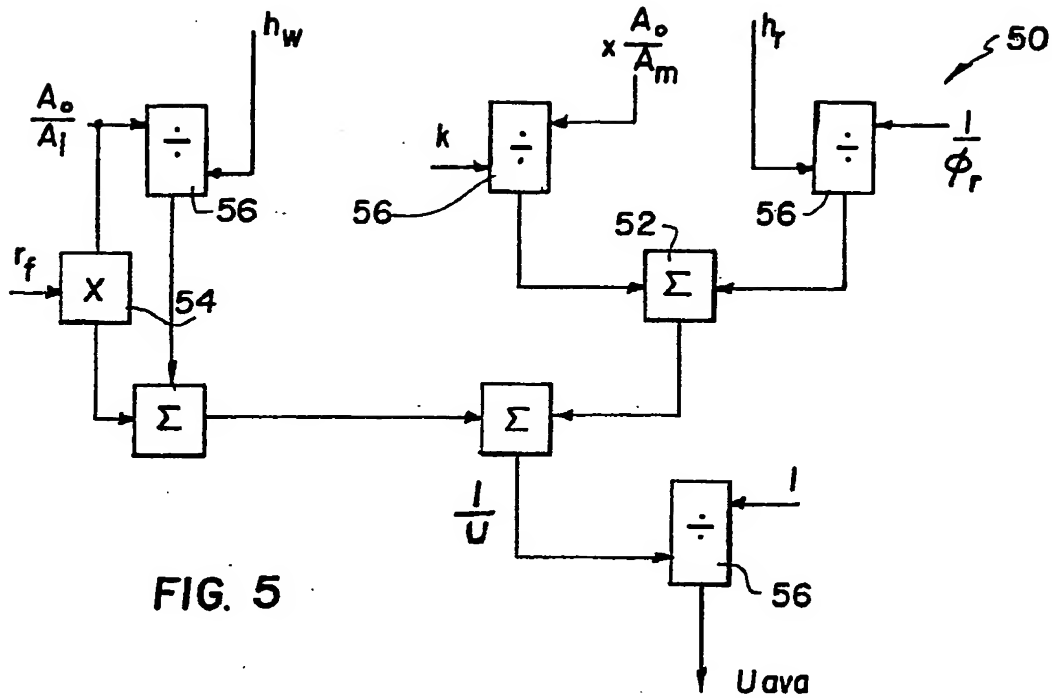

TT 1
TT 2
FT 1
FT 2
TT 3
LT 1
30
32
34
0.5
31
T_W
M_W
$f(T_W)$
$f(M_W)$
h_w
h_r
36
T_S
h_r°
Initialize as h_w°
$f_T(T_S)$
38
1
1/v
v
K_1
K_2
Optional Module
h_w°
h_w
T_S

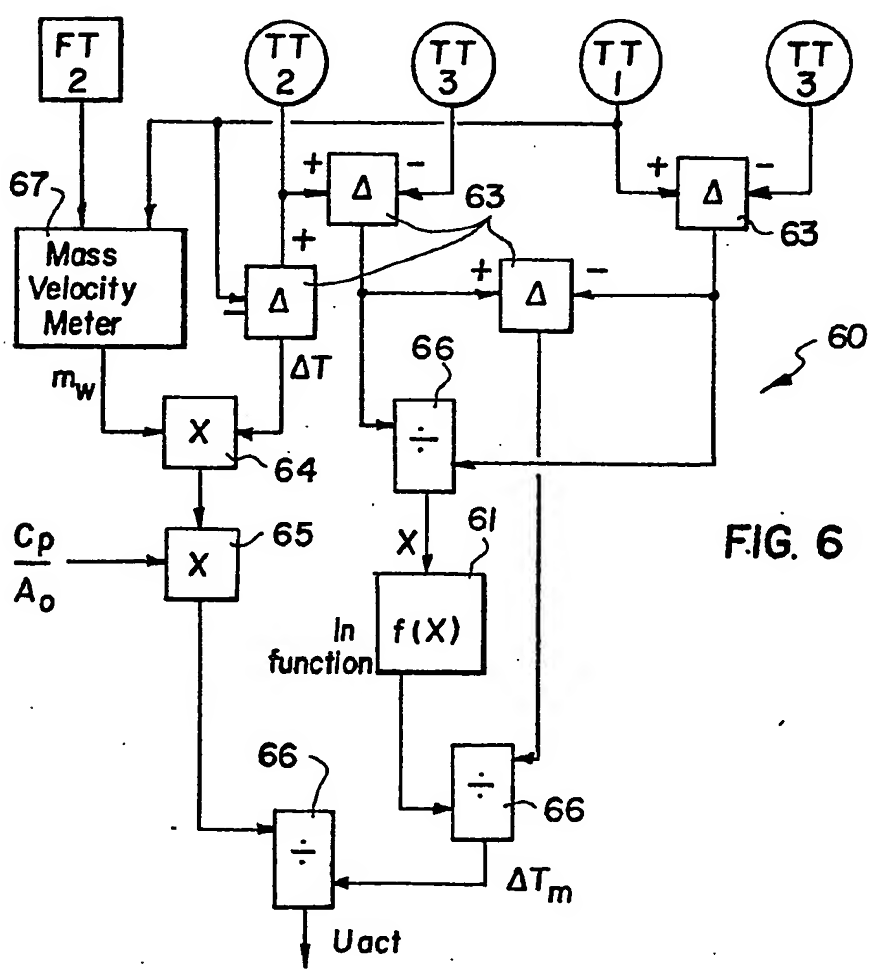
FIG. 4

FIG. 3



h_w
$\frac{A_o}{A_l}$
$x \frac{A_o}{A_m}$
h_r
50
k
$\frac{1}{\phi_r}$
56
56
52
56
r_f
X
54
Σ
Σ
Σ
$\frac{1}{U}$
1
56
Uava

FIG. 5



FT 2
TT 2
TT 3
TT 1
TT 3
67
Mass Velocity Meter
63
63
m_w
ΔT
66
60
64
65
$\frac{Cp}{A_o}$
X
61
ln function
f(X)
66
66
ΔT_m
Uact

FIG. 6